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Assessment of Fluoride Concentrations in Drinking Water Sources in the Jirapa and Kassena-Nankana Municipalities of Ghana

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Abstract

Fluoride is an important chemical for human health. However, its deficiency or excess in the human body poses health problems. In Ghana, the geological formation in the Upper Regions exposes groundwater, the main source of drinking water to risk of excessive fluoride. The risk of population exposure to high fluoride is further increased by the consumption of large volumes of water due to the hot climate of the area. Based on a Risk Assessment and Risk Management (RARM) model to safe drinking water supply, this study assesses the extent of fluoride concentrations in drinking water sources in the Jirapa and Kassena-Nankana Municipalities of Ghana. A concurrent nested mixed method design, which emphasized quantitative data was adopted for the study. Data were gathered through household surveys with housekeepers, testing of fluoride levels in households' drinking water sources and in-depth interviews with hydrogeologists from the Community Water and Sanitation Agency (CWSA). From the results, fluoride concentrations in drinking water sources is generally moderate (0.7 – 1.5 mg/L). Only a few (1.4%) water samples, all from boreholes, exceeded the World Health Organisation (WHO)/Ghana Standard Authority permissible limit of 1.5 mg/L. This implies that boreholes classified as improved water sources do not necessarily deliver safe water. In the Sustainable Development Goal (SDG) era where access to safely managed water is central to the achievement of target 6.1, we call on stakeholders in the water sector to assess and manage improved water sources with high fluoride levels.

Keywords: Risk Assessment; Fluoride; Improved Water Sources; Borehole; Safely Managed Water; Ghana.

1 Introduction

Fluoride is an essential element for human health (Fawell et al, 2006; Smedley et al, 2002). However, its deficiency or excess in the human body poses health problems. The main source of fluoride ingestion into the human body is through drinking water (Community Water and Sanitation [CWSA], 2017; Fawell et al, 2006). Fluoride levels between 0.7 and 1.2 mg/L in drinking water promotes healthy teeth and bone development (Freeze and Lehr, 2009), but high intake of more than 1.5 mg/L can give rise to dental fluorosis and in extreme cases skeletal fluorosis (Fawell and Nieuwenhuijsen, 2003; Smedley et al., 2002). Conversely, low fluoride intake is associated with dental caries (Fawell et al., 2006). Dental decay is very high when fluoride concentrations in drinking water are less than 0.1 mg/L and low when concentrations are around 1.0 mg/L (Fawell et al, 2006; Edmund and Smedley, 1996). Although fluoride deficiency in the human body can have detrimental effects, it can easily be minimised through fluoridation, and is thus not usually of grave concern (Smedley et al, 2002).

Globally, over 200 million people are thought to be drinking water with fluoride in excess of the World Health Organization (WHO) guideline value of 1.5 mg/L, with a majority of these living in developing countries (Edmunds and Smedley, 2005; Smedley et al., 2002). In Africa, excessive fluoride in drinking water is a major cause of morbidity (Fawell and Nieuwenhuijsen, 2003; Howard et al., 2012; Malago et al., 2017). In response to this and other water borne related morbidities and mortalities related to water-borne contaminants, target 6.1 of the Sustainable Development Goals (SDGs) emphasized universal access to safely managed water by 2030. According to the Joint Monitoring Programme (JMP), a person is said to have access to safely managed water if it is obtained from an improved water source, located on premises, available when needed and free from contaminants (WHO/UNICEF Joint Monitoring Programme, 2015a, 2015b).

Fluoride occurrence in groundwater is closely linked to its abundance in minerals and rocks (Edmunds and Smedley, 2005). Fluoride constitutes about 0.06–0.09 percent of the Earth's crust (Fawell et al., 2006). Consequently, low to high concentrations of fluoride can be found in groundwater depending on the nature of the rock and minerals (Fawell et al., 2006). Fawell et al. (2006) noted that groundwater with high fluoride concentrations occurs in large and extensive geographical belts associated with sediments of marine origin in mountainous areas, volcanic rock, granitic rock and gneissic rock. Exposure to excessive fluoride is also influenced by climatic type. Consequently, people living in areas with hot climates are at particularly at risk of excessive fluoride intake due to their consumption of large volumes of water (Fawell et al., 2006). It is estimated that daily fluoride exposure in a temperate climate ranged from 0.6 – 2.0 mg per day (WHO, 1984).

The underlying geology in the Upper Regions of Ghana is largely characterised by crystalline basement rocks of granite and Birimian (Agyekum and Dapaah-Siakwan, 2008; British Geological Survey [BGS], 2000; Smedley et al, 2002). These are fluoride-bearing minerals (Alfredo et al 2014; Obuobie et al., 2016), and thus increase the risk of groundwater having a high fluoride concentration. The geology together with the hot climate in the area exposes the population to excessive fluoride (BGS, 2000; Craig et al., 2015). However, information on fluoride concentration in groundwater sources in the Upper Regions of Ghana is limited in space and content. In terms of coverage, most studies on fluoride concentration in the Upper Regions were conducted in Bongo District (Alfredo et al 2014; Apambire, 2001; Malago et al., 2017; Smedley et al, 2002). This perhaps is due to the prevalence of dental fluorosis in the Bongo District (Firempong et al., 2013; Smedley et al, 2002; STACC-Ghana; 2013).

In terms of content, many of the published studies on fluoride concentration in the Bongo District of the Upper East Region simply provide an account of fluoride levels in groundwater sources or aquifers (Alfredo et al., 2014; Smedley et al., 2002). Limited information exists on the level of compliance of drinking water sources to the WHO/Ghana guideline value of 1.5 mg/L. Likewise there is limited information on the level of population exposure to excessive fluoride in drinking water as well as the influence of geology on fluoride concentrations in groundwater sources. This study therefore sought to assess the extent of fluoride concentrations in drinking water sources in two study sites in the Upper Regions of Ghana. Specifically, the objectives of the study were to examine; (a) the scale of fluoride concentrations in drinking water sources; (b) level of compliance of drinking water sources to the WHO guideline and Ghana standard value of 1.5 mg/L; (c) the level of population exposure to excessive fluoride (> 1.5 mg/L); and (d) the influence of geology on fluoride concentration in groundwater sources. The findings of the study will illuminate policies, programmes and strategies on the supply of drinking water with acceptable levels of fluoride in the Upper Regions of Ghana and potentially beyond. The findings will also serve as a secondary source of information for future studies on fluoride concentrations in drinking water sources in Ghana.

The remainder of the paper is divided into six sections. The conceptual framework of the study is presented in section two, followed by the provision of background information on the study area in section three. Section four outlines the research methodology. The results of the study are presented and discussed in section five, while section six provides a conclusion to the paper.

2 Risk assessment and Risk Management Model for Safe Water Supply

Efforts to prevent death from water borne diseases or to reduce the burden of such diseases are bound to fail unless people have access to safe drinking water (WHO/UNICEF Joint

Monitoring Programme, 2006). In respect of the importance of safe water to human health, the human right to water, in part, states that every person must have access to quality drinking water (WHO, 2003). This can be achieved through the use of a Risk Assessment and Risk Management (RARM) model to safe drinking water supplies (Bartram et al., 2001; WHO, 2011). The approach entails a systematic risk assessment of drinking-water supply from source and catchment to the consumer, including the identification of ways in which unacceptable risks can be managed (Bartram et al., 2001). In order to identify unacceptable risk, assessed risk must be interpreted based on health guidelines/standards (WHO, 2011).

A risk assessment and risk management approach to safe water supply was adopted in this study as a guide for interpreting results. Specifically, the study was guided by Bartram et al. (2001) framework for risk assessment and risk management of drinking water supply (Fig. 1). The framework in its simplest form is an iterative process that involves assessment of environmental exposures to safe water supply, followed by assessment of risk, interpretation of risk (acceptable/unacceptable) based on health targets and management of unacceptable risk. The final stage before re-entering the process is to assess public health status to determine the efficacy of risk management interventions. The framework also shows that findings from assessments of environmental exposure can form the basis for the design and implementation of risk management interventions.

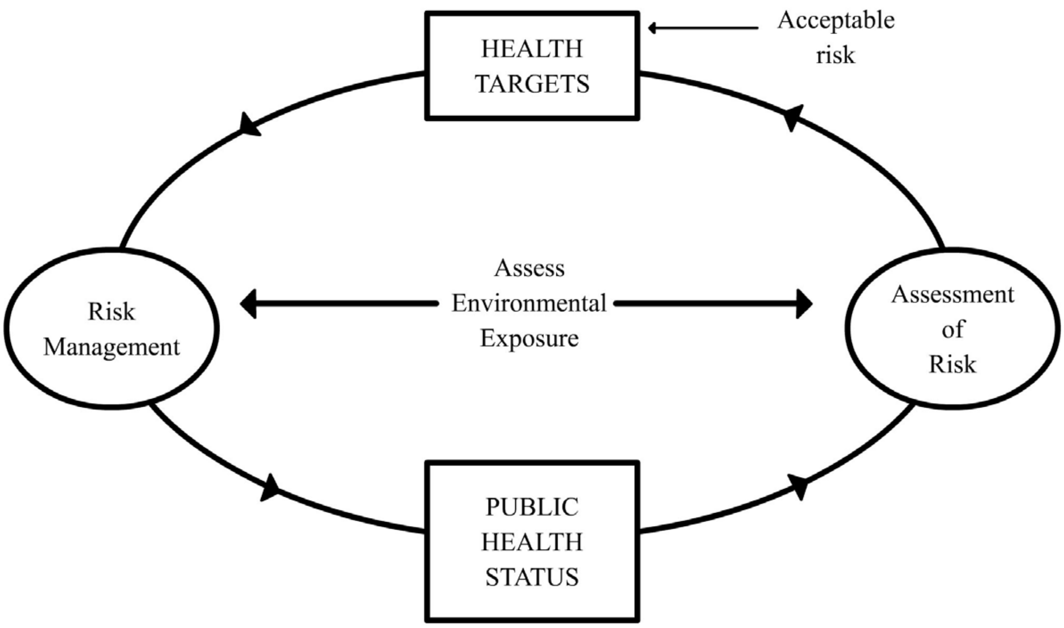

Fig. 1. Framework for Risk Assessment and Risk Management (RARM) of water-related infectious diseases (After: Bartram et al., 2001)

In line with the framework, fluoride assessment in drinking water sources was informed by two main environmental exposures following a review of literature. First, the geology in the Upper Regions, which is largely granite (Physical Panning Department, 2015), exposes groundwater to the risk of high fluoride concentrations. The risk is further increased by local populations consuming large volumes of water due to the region's hot climate. Fluoride concentrations recorded in drinking water sources were interpreted based on the WHO/Ghana maximum fluoride value of 1.5 mg/L. The rationale was to determine the proportion of water sources with/without acceptable fluoride risk. The results informed recommendations on the management of elevated fluoride risk in drinking water and on populations in the study area.

3 Study Setting

The study was conducted in the Upper West and Upper East Regions of Ghana where the geological formation exposes groundwater to high risk of fluoride concentration (BGS, 2000; Smedley et al., 2002). Due to financial constraint, Jirapa Municipality in the Upper West

Region and Kassena-Nankana Municipality in the Upper East Region (Fig. 2) were selected through a simple random sampling for data collection. A brief profile of each municipality is presented below.

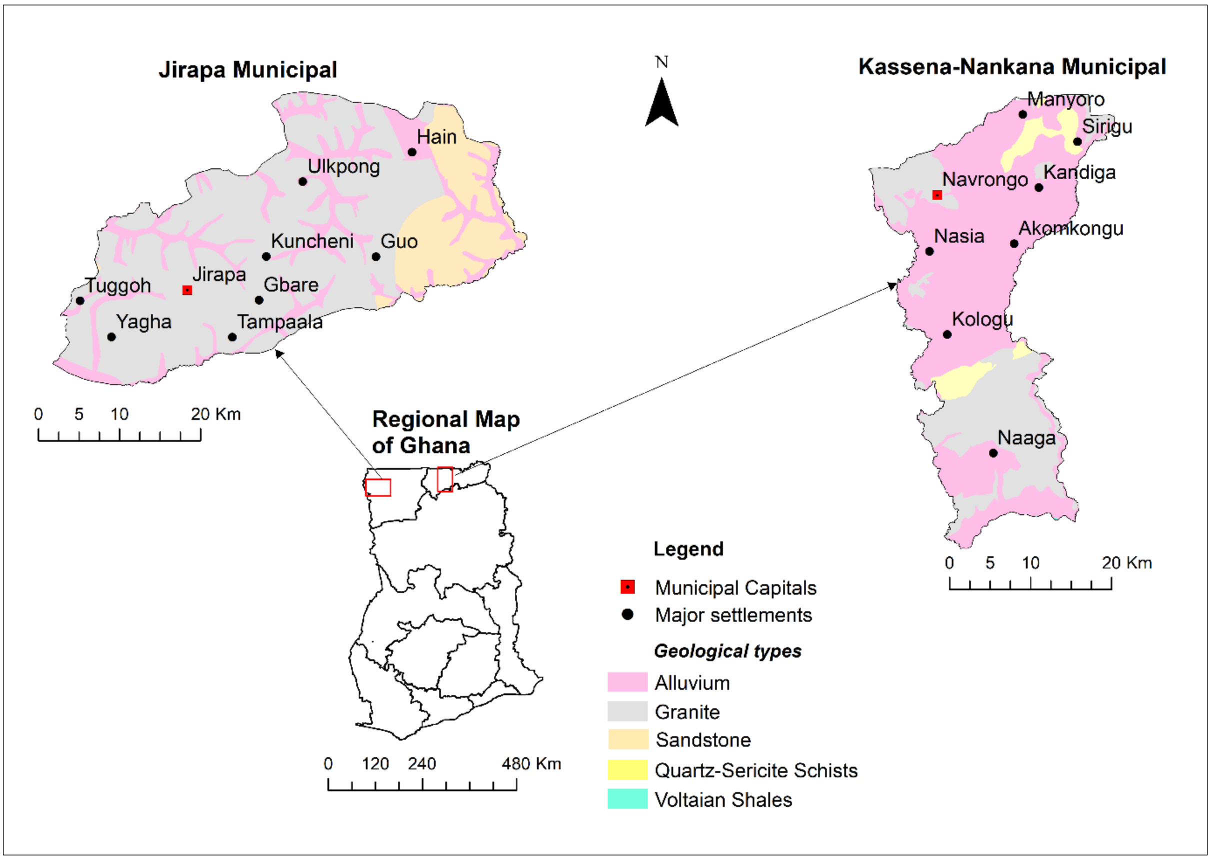

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Fig. 2. Locations of Jirapa and Kassena-Nankana Municipalities in Ghana

3.1 Kassena-Nankana Municipal

Kassena-Nankana Municipal is one of the 13 districts/municipalities in the Upper East Region of Ghana with the capital being Navrongo. It covers a total land area of 855 km^2 and lies between latitude 11°10' -10°3' North and longitude 10°1' West (GSS, 2014b). The municipality shares boundaries with Kassena-Nankana West District and Burkina Faso to the north, Kassena-Nankana West District and Bolgatanga Municipal to the east, Builsa District to the west and West Mamprusi District to the south.

From the 2010 Population and Housing Census, the municipality recorded a total population of 109,944 with females constituting 51.2% and males 48.8% (GSS, 2014b). Half (50.4%) of the population are between 0 and 19 years (GSS, 2014b). The Municipality is largely rural with seven out of every 10 people living in rural areas (GSS, 2014b). Furthermore, the 2010 PHC revealed that 93.2% of households in the municipality mainly drink from improved[1] water sources with a majority (64.6%) depending on boreholes (GSS, 2014b). Other improved water sources households depended on are pipe water system (15.2%), protected hand-dug well (9.9%), public tap/standpipe (2.5%), bottled/sachet water (0.4%), rainwater (0.3%), protected springs (0.2%) and tanker/vendor supply (0.1%) (GSS, 2014b). The remaining 6.8% of households relied mainly on unimproved[2] sources, comprising of unprotected hand-dug wells, rivers, streams, dams, dugouts, canals and ponds. The statistics showed that about 84% of households depended on groundwater sources (GSS, 2013b). This underscores the need for risk assessment and risk management of groundwater to enhance access to safe water.

A recent geological survey by the Physical Planning Department (PPD) of Ghana showed that the geology of the Municipality is dominated by alluvium (65%), followed by granite (30%) and quartz-sericite schists/Voltaian shale (5%) (Fig. 2). The geological distribution reported by the PPD of Ghana compared to earlier mapping exercises in the Upper East Region by the BGS (2000) revealed that the alluvium is a recent formation and may be underlain by either Birimian or granite. The BGS in the year 2000 reported that the Upper East Region is dominated by ancient crystalline rocks of granite (to the east, south and north-west) and Birimian (stretching

[1] Water source that by the nature of their construction and design are adequately protected from outside contamination, particularly faecal contamination; piped into dwelling, piped into compound, piped to neighbour, public tap/standpipe, borehole/tubewell, protected well, protected spring, rainwater, tanker-truck, cart with small tank/drum, water kiosk and bottled water (UNICEF/WHO, 2018).

[2] Water sources that by the nature of their design and construction are unlikely to deliver safe water; unprotected dug well, unprotected spring and surface water (UNICEF/WHO, 2018).

from north-east to south-west) as well as consolidated sedimentary rocks of Voltaian formation (covering a small belt in the south-eastern). The granite in the Upper East Region has fluoride-bearing-minerals of biotite, hornblende, amphibole, apatite and sphene (Agyekum and Dapaah-Siakwan, 2008; Edmunds and Smedley, 2005; Murray, 1960). Smedley et al. (1995) found that the granite extending from the north to the south of the region contains up to 0.2% of fluoride. This exposes groundwater in the region to a risk of high fluoride concentrations.

The Kassena-Nankana Municipality falls within the tropical continental climatic zone with one rainy season (GSS 2013b). Rainfall starts in April with low average monthly rainfall of about 30mm, increasing to a high of 260mm in August. It reduces suddenly to 50mm at the end of the rainy season in September (Agyekum and Dapaah-Siakwan, 2008). The rest of the year remains dry. Rainfall values in the area are among the lowest in the country and temperature values among the highest. Average monthly temperature ranges from 26.5 - 33^{o} C and between January and April, daily temperature can go as high as 42^{o} C (Agyekum and Dapaah-Siakwan, 2008). The high temperature in the area causes dehydration, resulting in the consumption of large volumes of water leading to a risk of high fluoride consumption.

Groundwater is the main source of water in the Upper East Region, including the Kassena-Nankana Municipality and is strongly influenced by rainfall, topography and the underlying geology (Obuobie et al., 2016). According to Agyekum and Dapaah-Siakwan (2008), aquifers are discrete, localised and discontinuous; with groundwater flow controlled by fracture intensity and the degree of interconnections. Boreholes constitute the main means of groundwater abstraction. Analysis of boreholes characteristics (Agyekum and Dapaah-Siakwan, 2008) revealed a depth range of 28 to 60 m.

3.2 Jirapa Municipal

Jirapa Municipal is one of the 11 districts/municipalities in the Upper West Region of Ghana. It is situated in the north-western part of Ghana with Jirapa as its capital (Fig. 2). The municipality is bordered to the south by the Nadowli-Kaleo District, to the north by the Lambussie-Karni district, to the West by Lawra Municipal and to the east by the Sissala West District. It lies approximately between latitudes 10.25^{o} - 11.00^{o} North and longitudes 20.25^{o} - 20.40^{o} West with a territorial size of 1,188.6 km^2 (GSS, 2014a).

Data from the Population and Housing Census (PHC) indicates that the municipality had a total population of 88,402 in 2010, comprising of 47% males and 53% females (GSS, 2014a). A majority (85.6%) of the population live in rural areas with the main source of livelihood being subsistence agriculture (GSS, 2014a). The sources of drinking water in the municipality include pipe-borne sources, standpipes, boreholes, hand-dug wells, rivers/streams, tanker/vendor supply, rainwater, sachet water and dam/dugouts. Data from the PHC indicated that in 2010, 91.6% of households used improved drinking water sources, mainly boreholes (75.1%). Like the Kassena-Nankana Municipality, a majority (71%) of the population depend on groundwater sources (GSS 2014a).

The Municipality, like the rest of the country, has a tropical climate. However, unlike southern Ghana with two rainy seasons, the entire Upper West region including the Jirapa Municipality experiences a single maxima rainfall regime from May to September, with average annual rainfall of about 115 cm (GSS, 2013a). The other half of the year remains dry and is characterised by cold and hazy weather from early November to March and intense hot weather that ends only with the onset of early rains in April (GSS, 2013a). The average monthly temperature ranges between 21ºC and 32 ºC. Temperatures rise to their maximum (40 ºC) in March, just before the onset of the rainy season (GSS, 2013a).

According to the Physical Planning Department of Ghana, the geology in the Jirapa Municipality comprises of granite (66%), sandstone (15%) and alluvium (19%) (Fig. 2). However, earlier mapping by the BGS (2000) classified the geology in the region to include granite (about 75%), Birimian (approximately 20%) and sedimentary rocks of Voltaian formation. As mentioned earlier, the alluvium reported by the PPD of Ghana appears to be a recent formation, and maybe underlain by Birimian and granite. The perennial flash floods the region has experienced over the past decade might have caused the deposition of alluvium in many areas. The granite in the Upper West Region is made up of biotite (Yendaw, n.d), a fluoride bearing mineral. The crystalline basement rocks in the region have well developed fractures, and hence the potential of obtaining groundwater in the region is high (GSS, 2014a, 2014b).

4 Methods

The study adopted a mixed methods research approach combining both quantitative and qualitative methods (Creswell, 2007; Creswell and Plano Clark, 2011). The rationale is to maximise the benefits of both methods in order to provide a better understanding of the phenomena under investigation (Creswell, 2007; Creswell and Plano Clark, 2011). Specifically, a current nested mixed methods design was employed (Terrel, 2012). This design placed priority on the collection, analysis and interpretation of quantitative data with less emphasis on qualitative data (Terrell, 2012).

Owing to limited resources vis a vis the need to gain an in-depth understanding of fluoride concentration in drinking water sources in the study area, one district from each of the Upper

Regions was randomly selected. Jirapa and Kassena-Nankana Municipalities were selected from the Upper West and Upper East Regions, respectively (Fig. 2). Three main data collection methods[3] were employed. They include questionnaire administration to housekeepers, testing of fluoride concentration in drinking water sources and in-depth interviews with Hydrogeologists of CWSA. Data collection spanned from June 2017 – February 2018. Each data collection method is discussed in detail below.

(a) Questionnaire Administration to Housekeepers

In order to meet the objectives of the study, data on household sizes, household drinking water sources and fluoride levels in drinking water were indispensable. Households therefore constituted the basic unit of analysis in this study. A representative sample of households was determined for the two sampled Municipalities based on Taro (1970) sample size formula;

$$n = \frac{N}{1+Ne^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equ. 1}$$

Where n = Sample size

N = Population (33,701)[4]

e = Sampling error (±5%)

From Equ. 1, a sample size of 395 households was obtained, and distributed proportionally between the two sampled Municipalities - Jirapa (163) and Kassena-Nankana (232). However, during data collection the targeted sample was exceeded by 40%. At the end, data were gathered from 568 households i.e., 268 in Jirapa Municipality and 300 in Kassena-Nankana Municipality. In each Municipality, households were randomly drawn from five Electoral

[3] As indicated in the acknowledgment section, this paper was culled out of an ongoing PhD study. Hence, the data collection methods presented here are limited to those relevant to the article.

[4] Total number of households for both Jirapa and Kassena-Nankana Municipalities recorded in the 2010 Population and Housing Census (GSS, 2013a;2013b)

Areas; one each from the North, South, East, West and Central parts of the Municipalities. This ensured a good geographic spread in the selection of households.

A questionnaire was administered to housekeepers using *SurveyCTO* mobile data collection technology. The questions were programmed online and deployed to mobile phones via the *SurveyCTO* App. Due to high illiteracy in the study area, research assistants were trained to help administer questionnaires to respondents in their local dialects (Dagaare, Kasim and Nankam). At the household level, housekeepers were purposively chosen because of their key role in household management, including water collection. Questionnaire data were downloaded from the *SurveyCTO* platform in a csv file and exported to Statistical Package for Social Sciences (SPSS) for analysis. Simple percentages were generated on population distribution by drinking water sources and level of population exposure to fluoride in drinking water.

(b) *Testing fluoride concentrations in drinking water sources*

Fluoride concentrations in households' drinking water sources were monitored in each of the two randomly selected study Municipalities. In each municipality, the main source of drinking water for each sampled household was tested. In all, 141 water samples, from five different water sources were collected in the rainy season (Table1). This is far less than the 568 households surveyed because most households share water sources.

Testing of fluoride concentrations in drinking water sources was conducted in the field using a portable *Palintest visual standard comparator kit*. The test kit includes a contour colour comparator disc (CD179 fluoride), dilution tube with a 10 ml mark and a stirring/crushing rod. The Disc covers the range 0 - 1.5 mg/L fluoride in steps 0, 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4 and 1.5 (Palintest Ltd, n.d). In line with the test protocol, Palintest Fluoride No. 1 and Fluoride No. 2 tablets were added one after the other into a test tube filled with a 10 ml water sample and stirred to dissolve. After 5 minutes, a test tube was placed in the comparator and matched against contour colour discs. Results were read and recorded as mg/L Fluoride.

Data on fluoride concentrations in drinking water sources and relevant attribute data were captured in SPSS (v24) and analysed quantitatively. Frequencies and descriptive statistics were generated to understand variations in fluoride concentrations in the study area by source types, districts and geological formations. A Mann-Whitney U test was carried out in SPSS to ascertain if fluoride concentrations in aquifers vary significantly by geological types. This was complemented by a spatial mapping of fluoride concentrations by geological types in ArcMap (v10.4.1).

In order to appreciate the proportion of drinking water sources that comply or do not comply with the WHO/Ghana Standard Authority fluoride guideline value of 1.5 mg/L., drinking water sources were classified into levels based on the amount of fluoride concentration. The study adopted a classification system provided by Smedley et al. (2002) in their assessment of fluoride concentrations in the Upper East Region of Ghana and parts of central Tanzania. Smedley et al. (2002) classified fluoride concentrations in drinking water into four levels as follows; < 0.7 mg/L (low), 0.7 -1.5 mg/L (moderate), 1.6-2 mg/L (high) and >2 mg/L (very high). Aside from the fact that this classification is consistent with the WHO/Ghana Standard Authority permissible limit of 1.5 mg/L, it allows detailed analysis of concentration levels.

(c) In-depth interviews with Hydrogeologists of the Community Water and Sanitation Agency

In both Jirapa and Kassena-Nankana Municipalities, in-depth interviews were conducted with hydrogeologists of the CWSA to elicit their views on the levels of fluoride concentration in drinking water sources and risk management interventions, if any, in their respective Municipalities. Data were also gathered on local geological formations, hydrology and depth of groundwater sources in the study area. Interviews were recorded, transcribed and analysed thematically (Rapley, 2011; Srivastava & Thomson, 2009). The results were triangulated with the quantitative data to enrich the findings of the study.

5 Results and Discussions

The results and discussions are sub-divided into five sections. The first section addresses household drinking water sources in the study area. This is followed by the scale of fluoride concentration in drinking water sources, level of compliance of drinking water sources to fluoride guidelines, levels of population exposure to excessive fluoride in drinking water and finally, the influence of geology on fluoride concentrations in groundwater sources.

5.1 Drinking Water Sources

Households in the study area depend not only on improved water sources but also on unimproved sources for domestic use. These include piped water systems into household compounds, standpipes, boreholes, protected hand-dug wells, rainwater (improved sources), unprotected hand-dug wells and dugouts/dams (unimproved sources) as shown in Fig. 3. Unlike protected and unprotected hand-dug wells, boreholes are mechanically drilled wells that are fitted with hand pumps. According to the Upper West Regional hydrogeologist, the depth of most boreholes in the study area is around 50 m while protected and unprotected hand-dug wells are 4 – 10 m deep. Edmunds and Smedley (2005) and Agyekum and Dapaah-Siakwan (2008) reported similar depths for boreholes and hand-dug wells in the Upper East Region. Protected wells are covered and lined (plastered with cement). Conversely, unprotected wells are not covered and the insides of most are unlined. Some protected wells have hand pumps fitted on them. Water is drawn from unprotected wells and protected wells without pumps by means of a bailer.

Standpipes are mechanically drilled like boreholes but use electric power to pump water from underground. In both Jirapa and Kassena-Nankana Municipalities piped water into compounds was found to be obtained from standpipes and treated at a centralised reservoir before being supplied to households through a network of pipes. In addition to the above sources, some households also relied upon dams and dugouts. Dugouts are very shallow hand-dug wells (less than 2 m deep) located in low-lying areas, mostly by a dam or pond.

A) Borehole in Piiyiri B) Dam and Dugout in Naagah C) Unprotected hand-dug in Tuggoh

D) Unprotected hand-dug well in Tuggoh E) Dam in Naagah

F) Standpipe in Kologu G) Protected hand-dug well in Kologu H) Piped water system connected into compound

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Source: Field survey, 2017

Fig. 3. Selected photographs of drinking water sources in the study area

A cross-tabulation of households' main drinking water sources with household sizes revealed that 97.4% of the population drink from improved water sources. From Fig. 4, access to improved water in Kassena-Nankana Municipality (98.2%) is slightly higher than in Jirapa Municipality (96.7%). In both Municipalities, over 90% of the population depend on boreholes (Fig. 4). This underscores the importance of groundwater to residents in the study area. Only 1.9% of the population have access to piped water systems in their compounds. Piped water systems into compounds were only found in the Municipal capitals (Navrongo and Jirapa) because it is highly expensive to provide a supply in rural areas where settlements are dispersed.

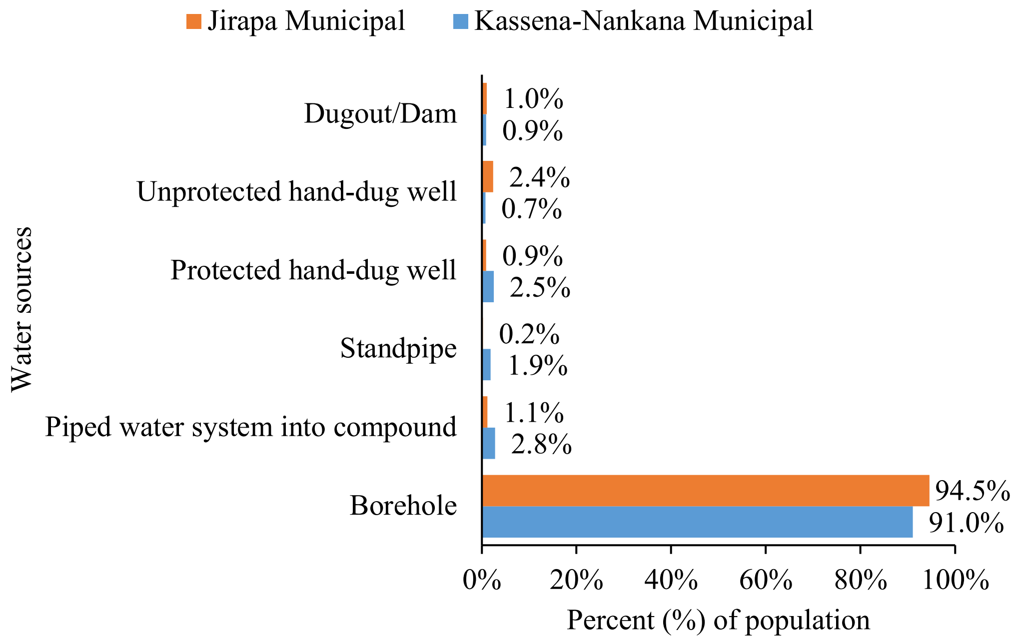

Fig. 4. Sources of drinking water in Jirapa and Kassena-Nankana Municipalities
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When compared to the 2010 Population and Housing Census, the findings showed a slight improvement in improved water coverage from 91.6% and 93.2% access to improved water sources in Jirapa and Kassena-Nankana Municipalities respectively and an average of 92.4% (GSS, 2014a; GSS, 2014b). The improvement in improved water coverage over the past eight years largely reflects the construction of boreholes by the central government, District

Assemblies, Non-Governmental Organisations (NGOs) and Parliamentary Representatives or Aspirants.

5.2 Scale of Fluoride Concentration in Drinking Water Sources

Fluoride concentrations in drinking water sources in the study area ranged from 0.6 – 2 mg/L, with the average being 1.0 mg/L (Table 1). Echoing a study by Smedley et al. (1995), the highest concentration was found in borehole waters while the minimum value was recorded in all sources except piped water systems into compound and dugouts/dams. Analysis of the average concentrations revealed a modest disparity in fluoride concentrations in drinking water by source types. Standpipe and borehole sources recorded the highest average concentration value of 1.1 mg/L, followed by protected hand-dug wells, unprotected hand-dug wells, dugouts/dams (1.0 mg/L) and lastly piped water systems into household compounds (0.7 mg/L) (Table 1). The relatively high fluoride concentration in standpipes and boreholes is because they draw water from deep underground (around 50 m) where strong water-rock interaction occurs (Edmunds and Smedley, 2005; Obuobie et al., 2016). Although piped water systems into compounds are sourced from mechanized boreholes which also draw water from deep underground wells, the low fluoride concentrations could be due to treatment effects. Low concentrations recorded in hand-dug wells and dugouts/dams compared to standpipes and boreholes reflect the fact that they are shallow (less than 10 m deep), resulting in little water-rock interaction. According to Edmunds and Smedley (2005), water at such shallow depths recirculates within the superficial weathered overburden layer rather than deeper, fractured rocks. Alfredo et al. (2014) and Smedley et al. (2002) in their studies found that although the Vea dam in the Upper East Region is located within the Bongo granite - a notable high fluoride area - fluoride concentrations were low due to little water-rock interaction. The slight variation in fluoride concentrations among drinking water sources could reflect the low number of samples collected for some water sources, especially standpipes (5), unprotected hand-dug wells (7) and dugouts/dams (2).

Table 1. Descriptive statistics on fluoride concentrations (mg/L) in drinking water sources

Water sources	Municipality	Minimum	Maximum	Average	No. of samples
Piped water system into compound	Jirapa	0.6	1.2	0.7	5
	Kassena-Nankana	0.6	1.0	0.8	5
	Total	0.6	1.2	0.7	10
Standpipes	Jirapa	1.0	1.0	1.1	1
	Kassena-Nankana	1.0	1.2	1.0	4
	Total	1.0	1.2	1.1	5
Borehole	Jirapa	0.6	1.5	1.2	52
	Kassena-Nankana	0.6	2.0	1.0	57
	Total	0.6	2.0	1.1	109
Protected hand-dug well	Jirapa	1.4	1.4	1.4	1
	Kassena-Nankana	0.6	1.2	0.9	7
	Total	0.6	1.4	1.0	8
Unprotected hand-dug well	Jirapa	1.0	1.4	1.3	4
	Kassena-Nankana	0.6	0.6	0.6	3
	Total	0.6	1.4	1.0	77
Dugout/Dam	Jirapa	1.2	1.2	1.2	1
	Kassena-Nankana	0.8	0.8	0.8	1
	Total	0.8	1.2	1.0	2
All sources	Jirapa	0.6	1.5	1.1	64
	Kassena-Nankana	0.6	2.0	0.9	77
	Total	0.6	2.0	1.0	141

As the descriptive statistics in Table 1 illustrate, slight differences exist in the scale of fluoride concentrations in drinking water sources between Jirapa and Kassena-Nankana Municipalities. The average fluoride concentration in Jirapa Municipality (1.1 mg/L) is 0.2 mg/L higher than in Kassena-Nankana Municipality (0.9 mg/L). However, in Kassena-Nankana Municipality, the highest fluoride concentration was 2.0 mg/L compared to 1.5 mg/L in Jirapa Municipality.

Findings from interviews held with the hydrogeologists of CWSA in both Kassena-Nankana and Jirapa Municipalities on fluoride concentrations in drinking water corroborated the quantitative data. Both hydrologists indicated that fluoride concentrations in drinking water in their respective Municipalities is generally within the WHO/Ghana Standard Authority recommended limit of 1.5mg/L. However, in Kassena-Nankana Municipality, the hydrogeologist stated that there is a possibility of high fluoride concentrations because of reported cases of high fluoride and dental fluorosis in neighbouring districts. He attributed the inability of the CWSA to confirm this potentiality to limited funds to undertake water quality testing. Also, water users rarely test and report the quality of their water sources to the agency, except where the agency is involved in the construction of the water source.

The average fluoride concentration recorded in this study for all sources (1.1 mg/L) is consistent with the findings of Smedley et al. (2002) in the Bolgatanga, Bongo and Tongo areas of the Upper East Region. However, Smedley et al. (2002) recorded much lower and higher concentration values compared to this study. The minimum and maximum concentration values reported by Smedley et al. (2002) were 0.1 mg/L and 4.4 mg/L, respectively. Another study by Smedley et al. (1995) in the Bolgatanga and Sekoti areas of the Upper East Region recorded fluoride concentrations of up to 3.8 mg/L in groundwater. The generally low levels of fluoride recorded in drinking water sources compared to Smedley et al. (1995)[5] and Smedley et al (2002)[6] which were conducted in the dry season could be due to a dilution effect because water samples were collected and tested in the rainy season (Fawell et al., 2006).

[5] Samples were collected and analysed in January 1993
[6] Samples were collected and analysed in February 2002

5.3 Level of Compliance of Drinking Water Sources to Fluoride Guidelines

A majority (98.6%) of drinking water sources in the study area complied with the WHO /Ghana standard value of 1.5 mg/L (Fig. 5). Only 1.4% of drinking water sources did not comply. Some 24.1% samples were deficient in fluoride with concentrations of less than 0.7 mg/L. Analysis by source type revealed 100% compliance for all sources except boreholes (98.2%). This implies that not all boreholes are safe for drinking. Although all unimproved sources complied with the fluoride concentration guideline, they are not safe for consumption due to a high risk of bacterial contamination (Edmunds and Smedley, 2005).

Between Jirapa and Kassena-Nankana Municipalities, modest differences exist in the level of compliance (Fig. 6). All drinking water sources in Jirapa Municipality complied with the WHO/Ghana guideline whereas in Kassena-Nankana Municipality, 2.6% of drinking water sources did not. The level of non-compliance of water sources recorded in this study (1.4%) is 21.2% lower than that reported by Smedley et al. (2002) in the Bolgatanga-Bongo area of Ghana.

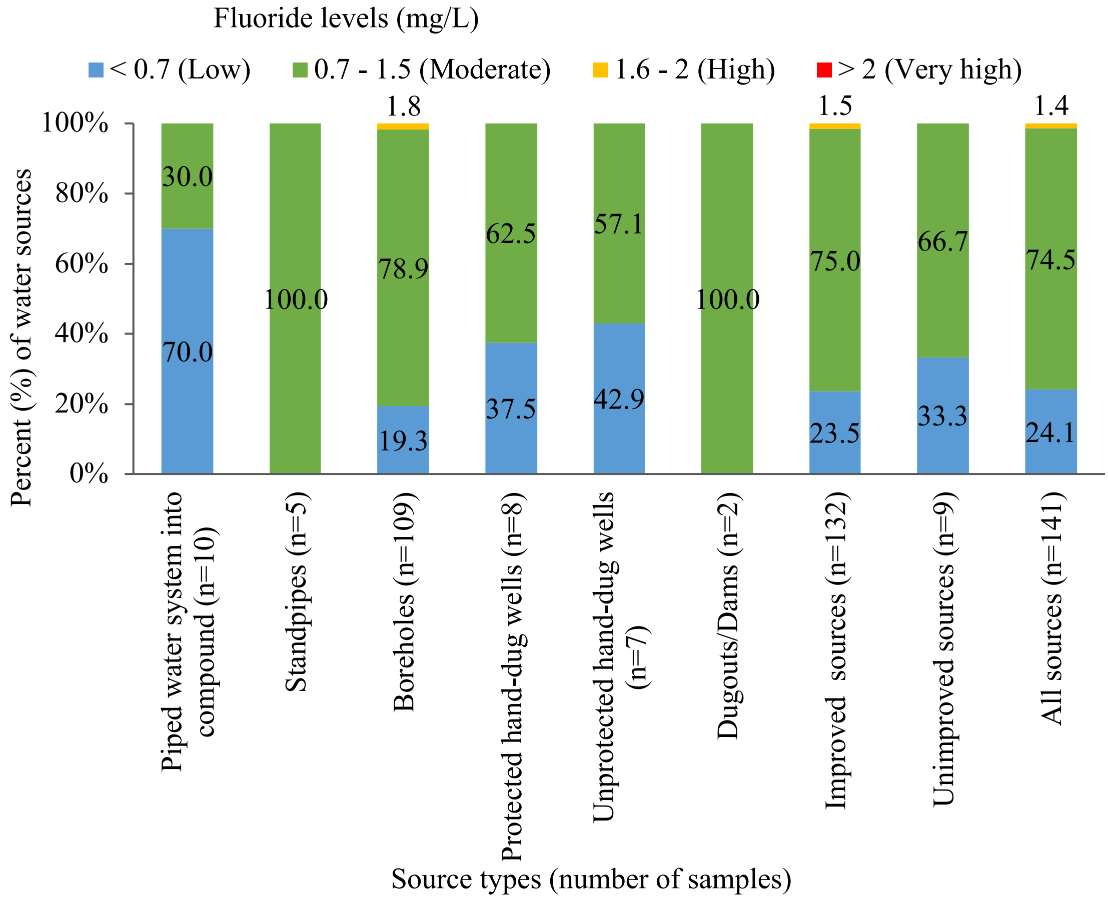

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Fig. 5. Level of fluoride concentrations in drinking water by source types

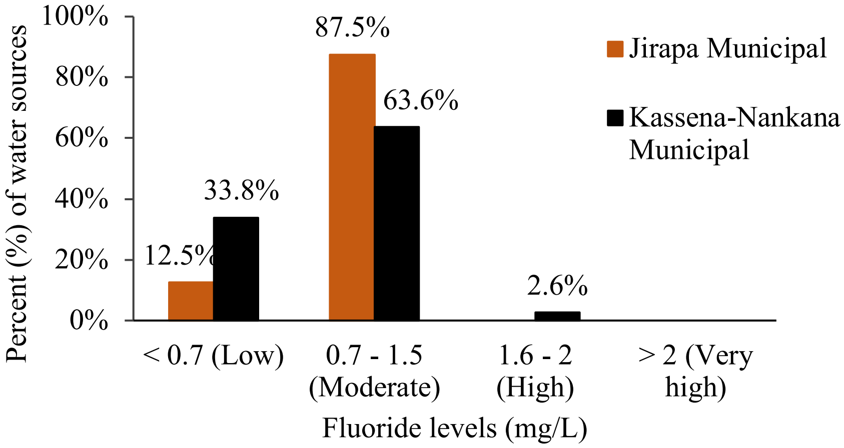

Fig. 6. Levels of fluoride concentrations in water sources by Municipalities
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5.4 Population Exposure to Excessive Fluoride Concentrations in Drinking Water Sources

In line with the WHO/Ghana guideline value, any person whose drinking water has fluoride concentrations above 1.5 mg/L is exposed to excessive fluoride and hence at risk of health problems linked to dental or skeletal fluorosis. A cross tabulation of fluoride levels in drinking water sources with household sizes reveals that only 1.5% of the population in the study area are exposed to high fluoride concentrations through drinking water (Fig. 7a). The remaining 98.5% drink from sources with acceptable fluoride concentrations (Fig. 7a). Paradoxically, the 1.5% of the population that are exposed to high fluoride drink from boreholes, which are generally associated with the delivery of safe drinking water. In Jirapa Municipality, no person was exposed to high fluoride in drinking water because all water sources have concentrations below 1.5 mg/L (Fig. 7c). From observation, cases of dental fluorosis were non-existent in Jirapa Municipality. In Kassena-Nankana Municipality, the results show that 3% of the population are exposed to high fluoride (>1.5 mg/L) (Fig. 7b) although few cases of dental fluorosis were observed. This condition imposes a lot of stigma on peope affected by it who often suffer from low self-esteem and limited socialisation (St. Andrews Clinic for Children-STACC, 2013; Nasirudeen, 2015). Schoolchildren with dental fluorosis who cannot withstand ridicule from peers sometimes drop out of school (Nasirudeen, 2015).

Previous studies (Edmunds and Smedley, 2005; Firempong et al., 2013; Nasirudeen, 2015; Smedley et al., 2002; STACC, 2013) reported a high prevalence of dental fluorosis in neighbouring Districts of the Kassena-Nankana Municipality. Edmunds and Smedley (2005) found that dental fluorosis was widespread in the Bolgatanga area due to high fluoride concentrations in groundwater. The problem they noted is highly prevalent in the Bongo and Sekoti Districts and common among children. Firempong et al. (2013) reported the prevalence of dental fluorosis among schoolchildren in and outside the Bongo Township of the Upper East Region to be 63% and 10%, respectively. Similarly, Smedley et al. (2002) estimated the prevalence of dental fluorosis among schoolchildren in Tarongo areas of the Bongo District to be between 20 - 50%.

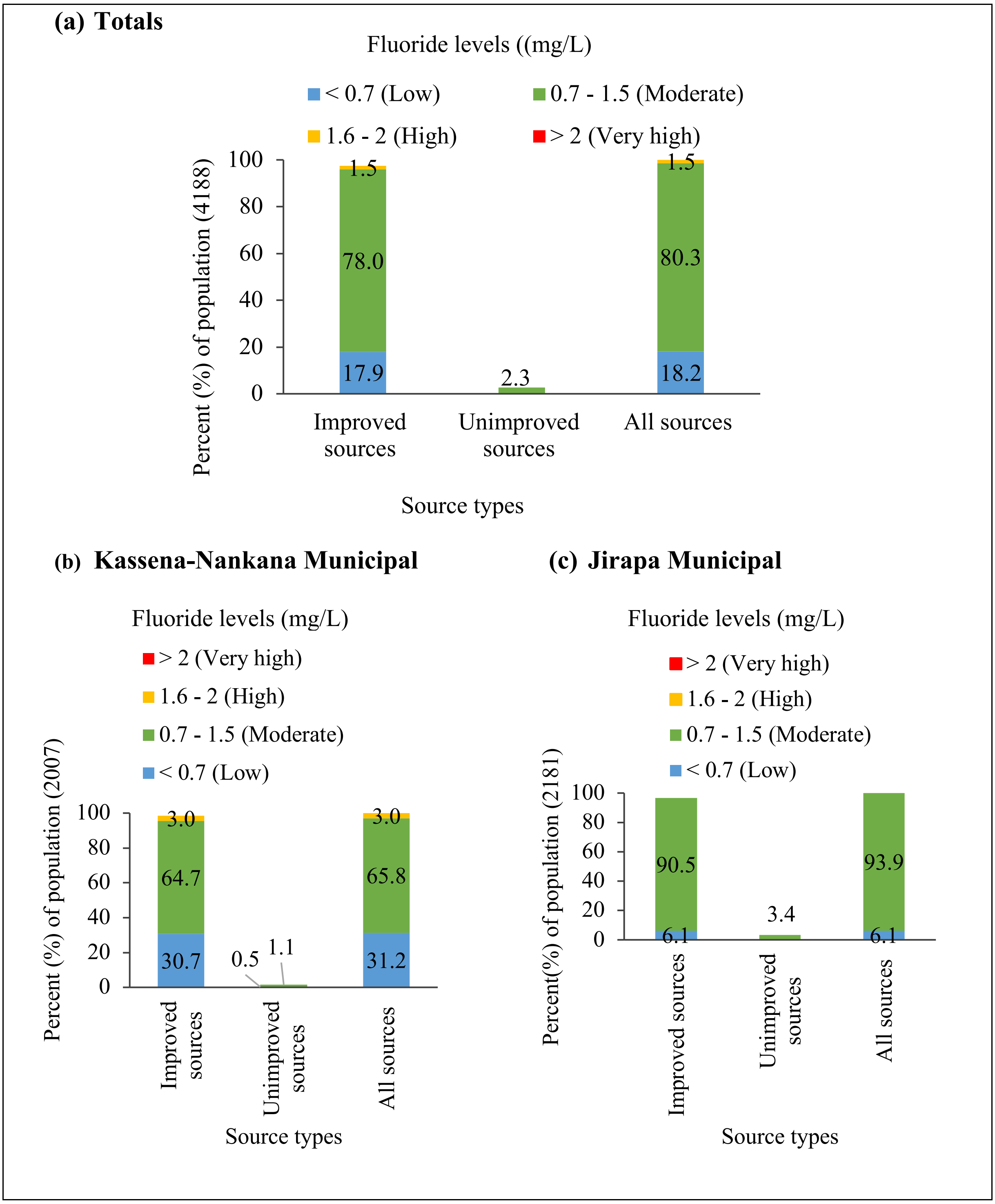

Fig. 8. Level of fluoride concentration in drinking water by population
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5.5 Influence of Geology on Fluoride Concentrations in Groundwater

With geology being the source of fluoride in groundwater, this section sought to find out if fluoride concentrations in groundwater vary by geological types. The 10 samples collected and tested from piped water systems into compounds were excluded from the analysis because water from pipes does not come directly from the ground but via a centralised system where treatment takes place. This reduced the number of samples from 141 to 131. A spatial overlay of the 131 water points with geological data reveals that samples were drawn from three different geological systems - alluvium, granite and quartz-sericite schists. The number of samples from alluvium, granite and quartz-sericite schists were 71, 59 and 1, respectively. The one sample from quartz-sericite schists was excluded from the analysis because it was considered insignificant for a meaningful statistical analysis.

Analysis of descriptive statistics reveal mixed findings on the association between geological systems and fluoride concentrations in groundwater sources for all samples (Table 2). The maximum value recorded in alluvium formation (2.0 mg/L) was higher than in granite. However, the average concentration in granite (1.1 mg/L) was slightly higher than in alluvium (1.0 mg/L). The minimum concentration value recorded in both geological systems was the same (0.6 mg/L).

Table 2. Descriptive statistics of fluoride concentrations (mg/L) in aquifers by geological types

	Geological types	Minimum	Maximum	Average	No. of samples
All sources	Alluvium	0.6	2.0	1.0	71
	Granite	0.6	1.5	1.1	59
Jirapa	Alluvium	1	1.4	1.2	11
	Granite	0.6	1.5	1.2	48
Kassena-Nankana	Alluvium	0.6	2.0	1	60
	Granite	0.6	1.2	0.7	11

At the Municipal level, the descriptive statistics also revealed mixed findings on the association between fluoride concentrations in groundwater sources and geological systems in Jirapa Municipality (Table 2 and Fig. 9). The minimum concentration value recorded in granite was lower than in alluvium while the maximum concentration value recorded in granite was higher than in alluvium. The average fluoride concentration in both alluvium and granite formations was the same (1.2 mg/L). In Kassena-Nankana Municipality, analysis of the average and maximum fluoride concentrations between the two geological systems reveals slightly higher fluoride concentration values in alluvium compared to granite. From Fig. 8, the two water samples with high fluoride concentrations were both associated with alluvium formations in the Kassena-Nankana Municipality. This contrasts with the findings of Smedley et al. (2002) who found a clear association between high-fluoride waters and the Bongo, Tongo and Sekoti Granites in the Upper East Region.

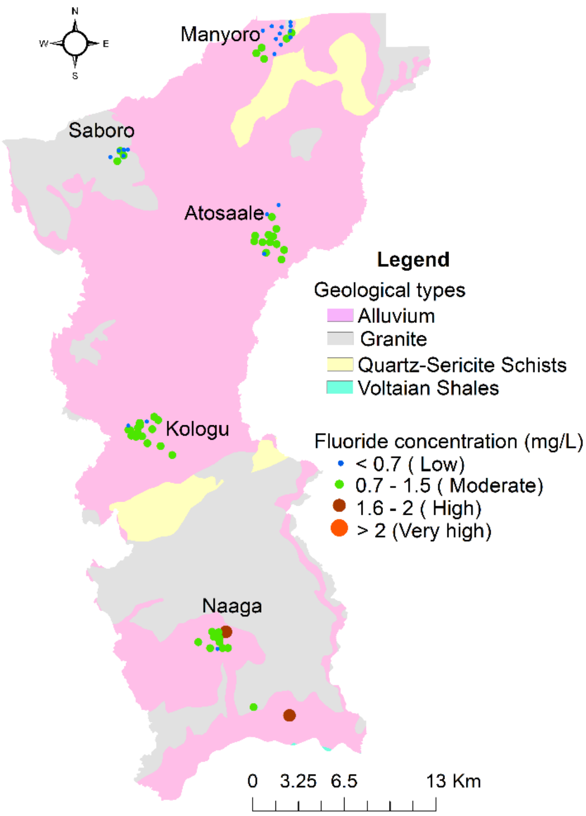

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Fig. 8. Distribution of fluoride concentration by geological types in Kassena-Nankana Municipality

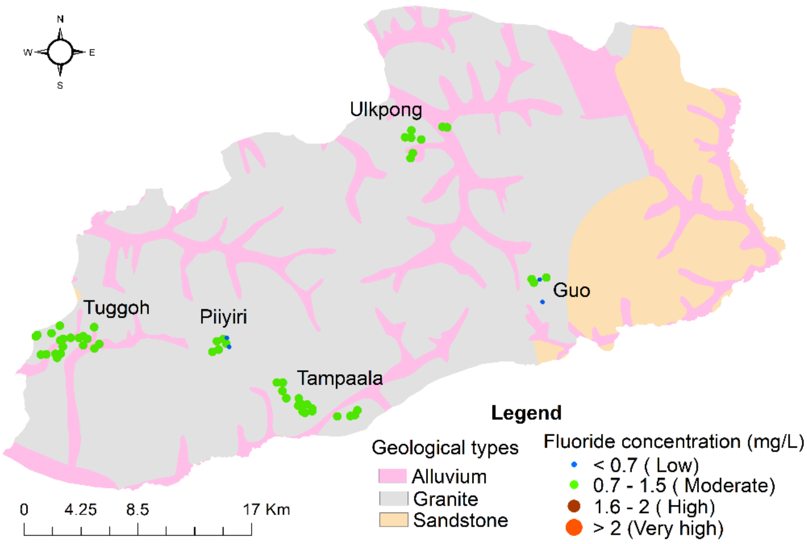

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Fig. 9. Distribution of fluoride concentration by geological types in Jirapa Municipal

A Mann-Whitney U test was employed to ascertain if the findings from the descriptive statistics were significant. Although the descriptive statistics revealed no clear association between fluoride concentrations in groundwater sources and geological systems for all samples, the Mann-Whitney U test showed otherwise. The test revealed a significant difference ($p<0.05$) in fluoride concentrations between alluvium and granite water samples (Table 3). From the average ranks, fluoride concentrations in granite were generally higher than in alluvium (Table 3).

At the Municipal level, the findings were contrasting. The Mann-Whitney U test statistics in Table 3 reveal significant variations in fluoride concentrations between geological systems in Kassena-Nankana Municipality ($P<0.05$). From the Mann-Whitney U test average ranks, concentration levels in the alluvium samples was higher than in the granite samples (Table 3). Unlike Kassena-Nankana Municipality, the association between fluoride concentrations and geological systems in Jirapa Municipality was not significant ($P>0.05$), although the Mann-Whitney U test average ranks reveal that concentration levels in granite samples were slightly higher than in alluvium samples.

Table 3. Mann-Whitney test statistics of fluoride concentrations by geological types

Test groups	Geological types	Number of samples	Average Ranks	Z-score	P value (2-tailed)
All samples	Alluvium	71	57.2	-2.864	0.004
	Granite	59	75.5		
Jirapa Municipal	Alluvium	11	25.7	-0.956	0.339
	Granite	48	31.0		
Kassena-Nankana Municipal	Alluvium	60	38.5	-2.517	0.012
	Granite	11	22.6		

6 Conclusions and Recommendations

The study set out to assess the extent of fluoride concentrations in drinking water sources in the Jirapa and Kassena-Nankana Municipalities of Ghana. From the water testing, fluoride concentrations in drinking water sources were generally moderate (0.7 – 1.5 mg/L). High fluoride concentrations (>1.5 mg/L) were recorded in only a few (1.4%) borehole samples in the Kassena-Nankana Municipality in the Upper East Region but revealed the potential for high fluoride in underlying bedrock, especially in the southern part of the Municipality. The high fluoride concentrations in water from boreholes also indicates that natural groundwater in the Kassena Nankana Municipality is not necessarily safe for drinking.

The findings reinforce the call by SDG target 6.1 for drinking water supply stakeholders to assess and manage fluoride levels and other contaminants of health significance in improved water sources as part of the drive to achieve universal access to safely managed water by 2030. In line with the Risk Assessment and Risk Management model (Fig. 1) safe drinking water supply, we call on the District/Municpal Assemblies and CWSA in the Upper Regions to undertake a comprehensive assessment of fluoride for all improved water sources. This should be followed by educating households on the use of low cost fluoridisation methods such as adsorption to treat drinking water with excessive fluoride. The District Assemblies should also pass a bye-law mandating individuals and organisations that supply water to obtain a certified risk assessment and risk management certificate from the CWSA. This certificate should be renewed periodically. Lastly, the impact of fluoride risk management interventions on local populations should be evaluated periodically.

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